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Procedia Engineering 60 (2013) 170 – 175

Procedia Engineering

www.elsevier.com/locate/procedia

6th Asia-Pacific Congress on Sports Technology (APCST)

Influence of protective pad integrated into sport compression garments on their pressure delivery to athlete's lower limbs

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Received 20 March 2013; revised 6 May 2013; accepted 9 May 2013

Abstract

This study aims to investigate the influence of the size of protective pad integrated into knitted fabric assembly intended for protective compression sport garments on the pressure delivery by the garment to the body of the wearer. A protective pad was integrated into an experimental knitted fabric sleeve assembly that resembled the knee section of a common compression garment. Several pads of different size were incorporated into the experimental fabric assemblies of the same dimensions and the effect of the pad size was determined. In addition, the dimensions of the fabric sleeve assemblies were varied with the size of the pad remaining constant. The pressures generated by the assemblies on a cylindrical model limb, and the physical and mechanical properties of the experimental fabrics were determined. The pressure generation properties of the sleeve assemblies were measured using Salzmann pressure-measuring device MST MKV IV. The results were analyzed and the influence of the protective pad on the garment pressure delivery to a cylindrical bluff limb, and thus potentially to the wearer's body, was determined.

Selection and peer-review under responsibility of the School of Aerospace, Mechanical and Manufacturing Engineering, RMIT University

Keywords: Protective pad; sportswear; compression garment; knitted fabric

1. Introduction

Physical activity and participation in sports and fitness is an integral part of a healthy lifestyle, and may reduce the risk of chronic diseases [1]. While these activities do not often result in fatalities, possible

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Selection and peer-review under responsibility of the School of Aerospace, Mechanical and Manufacturing Engineering, RMIT University
doi:10.1016/j.proeng.2013.07.056

injuries do represent a large burden on the health care system and often have long-term consequences, i.e., osteoarthritis [2].

Treating sports injuries is often difficult, expensive and time consuming [1], and thus attention to these injuries in the public health context is important. Changes in personal behaviour and environmental conditions can help reducing many kinds of injuries [3], however for a majority of sports and recreational activities the use of appropriate protective gear is crucial [2].

Protective pads such as rib protectors, hip pads, knee pads and the like are commonly worn by athletes in a variety of sports in which body contact with another participant presents a risk of injury to the athlete [2]. There are also other applications of the pads inserted into compression garments or specifically constructed fabric sleeves [5], such as for example Zhik PowerPads™.

Compression garment provides a means of applying mechanical pressure to the surface of the athlete's body, thereby compressing and potentially stabilizing/supporting the underlying tissue [4]. Sports compression garments have been used by athletes for years to enhance performance and to speed-up recovery; they are becoming increasingly popular for use in a multitude of sporting activities due to their claimed positive attributes [6]. In some cases compression garments incorporate some form of protective pads [7]. The majority of commercial branded compression garments currently available for sport applications are claimed to provide the wearer with enhanced blood flow, better muscle oxygenation, reduced fatigue, faster recovery, reduced muscle oscillation and reduced muscle injury [8].

Lawrence and Kakkar [9] suggested that an optimal applied pressure to generate the fastest venous flow is 18 mmHg at the ankle, 14 mmHg at the calf, 8 mmHg at the knee, 10 mmHg at the lower thigh and 8 mmHg at the upper thigh. This mainly applies to the extremities, but not to the trunk of the body.

The degree of pressure produced by a compression garment is determined by a complex interrelation between the following principal factors: the design and fit of the garment; structure and physical properties of the materials it is made from; the size and shape of the part of the body to which it is applied; and the nature of the sporting activity undertaken [8].

Under the assumption that there is an optimal pressure generated by a compression garment on a particular part of the body, there is a possibility that the incorporation of a protective pad into the garment will affect the optimal pressure generated or the pressure gradient. The present study aims to investigate the influence of the size and the design of protective pads integrated into a knitted fabric assembly on the pressure delivery by the protective compression garment to the limb of the wearer. The results are expected to be useful for design and engineering of protective compression sports garments.

2. Experimental

In this study, a protective pad was integrated into an experimental knitted fabric sleeve assembly that resembled the knee section of a sport compression garment. Several pads of different size and design were tested with experimental fabric sleeves of the same dimensions. The pad types used included a rigid pad (monolithic plate) and a flexible pad (a plate segmented into interlocked osteomorphic blocks), Fig. 1. The sleeves were then put onto rigid cylinder and the pressure generated by the sleeves was measured.

The use of the osteomorphic blocks [10] in protective pads is entirely novel. Not only does this pad design principle provide a pad with flexibility, but it also ensures high fracture toughness and tolerance to local failures.

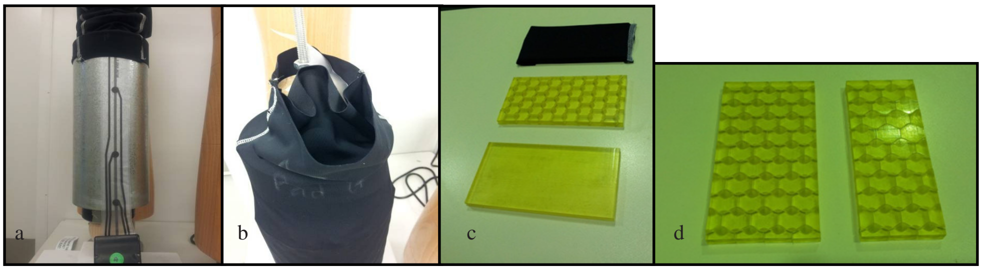


Fig. 1. a. Sleeve, cylinder, pressure sensor; b. pocket; c. inserted pad (monolithic plate, plate segmented into osteomorphic blocks, assembly of osteomorphic blocks inside a pouch); d. osteomorphic block assemblies of different size

The experimental cylinder was a rigid cylinder 13 cm in diameter and 30 cm in length. The diameter of the cylinder was comparable with a typical lower limb size of an athlete at the knee section [11]. The length of the cylinder was determined by the length of the sensor used for pressure measurement.

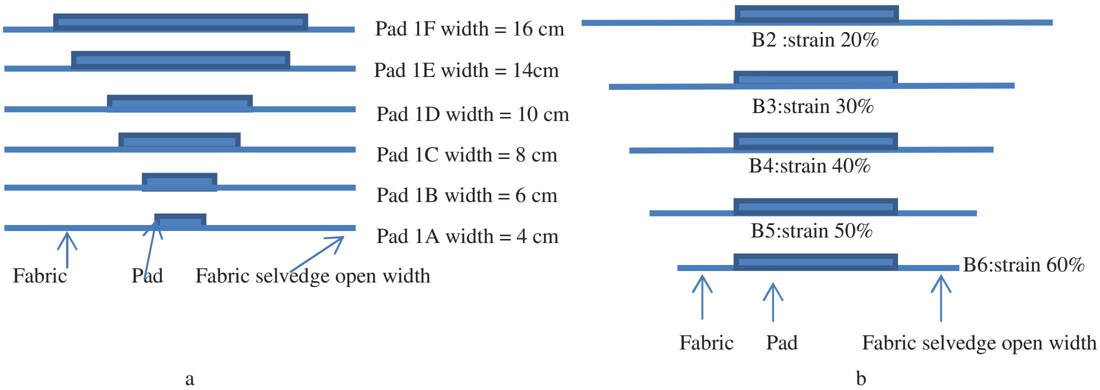


Fig. 2.a. Pads of different size on fabric layers (cross section); b. Same size pad on fabric with different elastic strains (cross section)

The sleeves were made from knitted fabric suitable for sport compression garment. The fabric size was 50 cm in length and 32.7 cm in width, so that the sleeve provided 25 % practical extension in fabric course direction (in width direction when worn on the cylinder). The seam allowance of 2 cm was added. The fabric was sewn into sleeves using 3 thread cover stitch. The pocket for the protective pad was made from the same fabric and was incorporated into the sleeve by seams. The protective pad was manually inserted into the pocket.

The pressure generated by sleeves was measured using Salzmann pressure-measuring device MST MK IV and Salzmann MST 2007 software. The measurement on the cylinder was conducted as follows: the cylinder was positioned vertically on its holder so the cylinder did not move. The sensor used was a "short" sensor that was attached to the top of the cylinder. The sleeve was positioned on the cylinder over the sensor and was spread evenly so there was no fold, kink or air "bag" underneath it. The sensor was connected to the Salzmann device with a computer attached, and then the pressure was measured using the Salzmann software.

Two types of size effect were studied: (i) the pad size was varied, while the fabric dimensions were kept constant and (ii) the fabric dimensions were varied with the size of the pad remaining constant, so that the sleeves provided different degree of extension around the circumference of cylinder.

The pressure measurements were conducted several times, and then the mean pressure was calculated. The influence of the protective pad on the pressure delivery of the fabric sleeve assembly to the experimental cylinder was analysed using correlation F-test, Student's t-test and ANOVA.

The physical and mechanical attributes of the comprising fabric were also determined. The mechanical properties were tested using an Instron tension tester. Fabric samples were tested for the extension at a specified force according to British Standard 14704-1:2005, which supersedes BS 4952;1992, in the wale (length-wise), course (width-wise) and bias direction with 5 specimens in each direction; and the mean values were calculated.

3. Results and discussion

The test result of physical properties of fabric and pads used in this study are given in Table 1, and the strain of fabric at a force of 25 N in four different fabric directions are given in Table 2.

Table 1. Fabric and pad properties

Physical Properties	Fabric	Pad	
		Monolithic Plate	Segmented Osteomorphic Block
Fibre Composition (%)	Nylon 80, Elastane 20	-	-
Mass/area (g/m^2)	234	11724	11724
Course density/cm	22	-	-
Wale density/cm	26	-	-
Thickness (mm)	0.69	9.83	9.80

Table 2. Extension at specified force

Mechanical properties	Strain (%)			
Force (N)	Direction			
	Course 0°	Bias 45°	Wale 90°	Bias 135°
25	149.5	153.7	210	164.4

Figure 3 shows the pressure delivery for pads of different size attached to the sleeve on the cylinder. *WP* and *OB* refers to sleeves without a pad and with an osteomorphic block pad, respectively. 1A-1F were sleeves with different size of the pad, 1A being the smallest and 1F the biggest size. It is seen that the pressure delivery slightly varied for different pad sizes.

To find the difference between *WP* an *OB*, statistical tests were carried out. Student's t-test procedures were used to determine the difference between the two population means. The F-test was conducted to determine the equality or homogeneity of variances to ascertain that the assumption of equal variance was valid so that Student's t-test procedure could be conducted. The null hypothesis (H0) for the test is that all population means (level means) are the same. The alternative hypothesis was that one or more population means differ from the others. Based on the F-test results, H0 ($p > 0.05$) was accepted for all groups, so that Student's t-test could be carried out. All Student's t-tests confirmed that the population averages were the same. The sleeves without a pad and those with *OB* pads generated practically the same pressure, and it can be concluded that incorporating an *OB* pad in a sleeve does not influence its pressure delivery

Furthermore, the test series 1A to 1F using one-way ANOVA returned similar results in that the pressure generated by the sleeves was practically not affected by the size of the inserted *OB* pad.

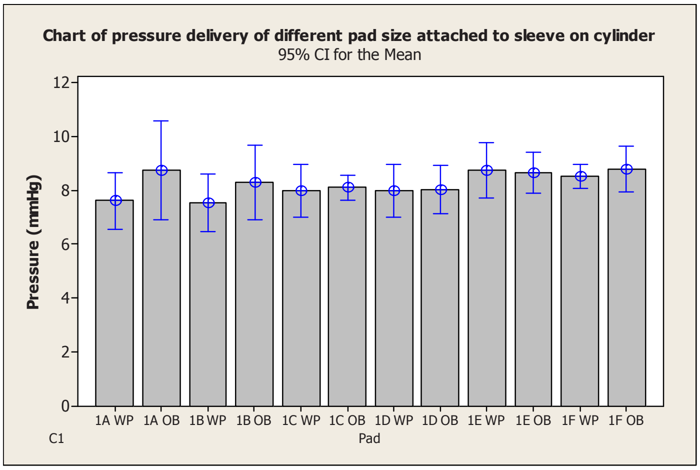
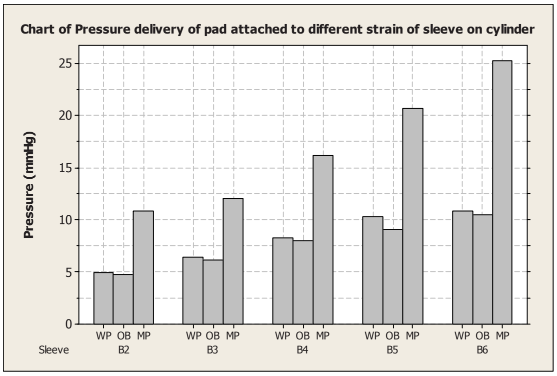


Fig.3. Pressure delivery for pads of different size attached to the sleeve on a cylinder (WP: no pad; OB: osteomorphic block pad)

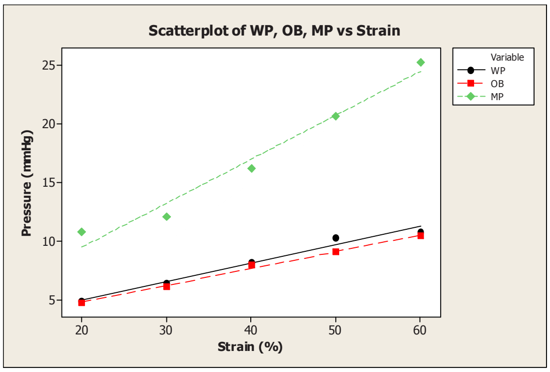
The results of pressure test for pads attached to the sleeve assembly under different fabric extensions on cylinder are presented on Fig. 4.a. The pressure produced in the presence of an inserted *OB* is seen to be slightly lower than that in the case of *WP*. Furthermore, the pressure levels generated by the monolithic plate pads (*MP*) were the highest among the three groups tested.

To verify the statistical relevance of the results for the pads of the same size attached to sleeves under different strains, the F-test and Student's t-test were performed.

From the results of F-test, the decision was to accept H0 ($p > 0.05$), so that Student's t-test could be performed. These confirmed that for both *WP* and *OB* cases the average values were the same. This provides statistical relevance to the observation that incorporating *OB* pads into compression garment did not affect the pressure delivery.



a



b

Fig. 4.a. Pressure delivery for pads attached to fabric under different strain (bar chart); b Pressure versus fabric strain

By contrast, all Student's t-tests for *WP* and *MP* suggested that H0 ($p < 0.05$) was to be rejected, which means the average for the *WP* and *MP* were not the same, i.e. the pressure delivery was different for the *WP* and *MP* cases. It means that incorporating *MP* in compression garment did influence the pressure delivery.

The dependence of pressure delivery on the fabric strain is presented in Fig. 4.b. An increase of pressure with strain is clearly seen for all three groups of tests.

4. Conclusions

Incorporation of a protective pad into the compression garment produced different outcomes in terms of the resultant pressure. The pressure delivery exhibited a dependence on the design of the pads: monolithic plate pad (rigid pad) inserted into garment sleeve did influence the pressure produced by the garment, while the osteomorphic block pad (flexible pad) did not. The pressure generated by fabric sleeves increased with the increase of its extension. No difference between garment without pad and that with osteomorphic block pad in terms of the pressure produced was recorded.

These results are of significance for design and engineering of protective compression sports garments. The designer should consider that the incorporation of rigid pads into garment will influence pressure delivery, so that the design needs to be adjusted accordingly. By contrast, the novel flexible pad suggested, viz. a plate segmented in topologically interlocked osteomorphic blocks, will not influence the generated pressure and its delivery, so that the initial garment design needs not be altered.

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